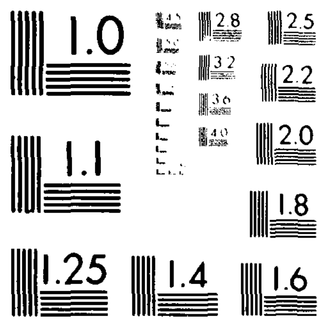
AD-A090 379 ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND DOVER--ETC F/G 11/6
POWDER METALLURGY STEEL FORGINGS FOR SMALL ARM APPLICATIONS,(U)
JUN 80 A CROWSON

UNCLASSIFIED NL

1 OF 1
AD A
090379

END
DATE
FILMED
11-80
DTIC




MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

# POWDER METALLURGY STEEL FORGINGS FOR SMALL ARM APPLICATIONS (U)

JUN 1980

ANDREW CROWSON PhD.
FIRE CONTROL AND SMALL CALIBER WEAPON SYSTEMS LABORATORY
U.S. ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
DOVER, NEW JERSEY 07801

## INTRODUCTION

Powder metallurgy (P/M) steel forging is a relatively new fabrication process. Although experimental activities date back to the early 1960's, it was not until the early 1970's that the process was fully developed as a viable manufacturing technique (ref 1-3). The process combines the advantages of fabricating net or near-net shape parts using conventional P/M processing and of property enhancement achieved by subsequent forging.

The basic process involves the following steps:

Powder ⟶ Preform ⟶ Sinter ⟶ Forge ⟶ Finish

First a mixture of prealloyed steel and graphite powder is compacted into a predetermined shape called a preform. The preform density is usually in the range of 80 to 88 percent of the theoretical density (7.87 $g/cm^3$). The preform is next heated under controlled conditions in a sintering step. This step reduces the undesirable inhomogeneties present in the starting powder, alloys the steel and graphite powders, and increases the strength of the preform. Following sintering, the forging operation is used to fully densify the preform. This is subsequently followed by a minimal number of finishing operations to obtain the final part.

The successful application of the P/M forging process to ordnance components offers substantial economic benefits. Primary cost advantages over the conventional processes lie in more efficient material utilization, simpler forging operations, and reduced finishing operations. With the P/M forging process a one step forming operation is used instead of the multiple operations required in conventional forging. Thus, scrap losses are reduced since the normal fullering, edging, blocking and flash removal operations of conventional forging are eliminated. Through the use of closed confined P/M forging dies closer tolerance parts are produced than with conventional forging. This reduces and, in some cases, eliminates the machining and surface finishing operations normally required to produce a part to dimensional tolerances. Consequently, by substituting P/M forging for conventional forging costs in the production of many load-bearing components can be reduced by 25-50 percent (ref 4-5).

## PROCEDURE

The following procedure was used in forming the P/M forged parts which provided the mechanical and physical property data reported in this paper.

Prealloyed 4600 powder was mixed with flake graphite to obtain a 0.4 percent carbon content (4640 steel). The basic composition of the powder along with the AISI specification for 4600 wrought material is given in Table 1. The powder mixture was compacted into 8.90 cm x

Table 1. Chemical Analysis of 4600 Prealloyed Powder

| Element | AISI Specification (%) | 4600 Powder (%) |
|---|---|---|
| Carbon | --- | --- |
| Nickel | 1.65-2.00 | 1.77 |
| Molybdenum | 0.2 -0.3 | 0.48 |
| Manganese | 0.6 -0.8 | 0.23 |
| Copper | --- | 0.05 |
| Chromium | --- | 0.05 |
| Phosphorus | 0.04 max | <0.01 |
| Sulfur | 0.04 max | 0.02 |
| Silicon | 0.02-0.34 | 0.07 |
| Oxygen | --- | 0.152 |

1.90 cm x 2.54 cm rectangular bars to 80 percent of theoretical density. Compaction was conducted using a closed confined die supported by springs. This enabled the compaction operation to simulate a double acting press, thereby producing compacts with uniform density profiles. The preforms were sintered in a 95 hydrogen-5 methane atmosphere for 40 minutes at

1200°C. Forging of the sintered preforms were carried out in a preheated confined forging die. Forging pressures were adjusted to achieve full densification. The forgings were subsequently austenitized for ½ hour at 843°C and tempered for one hour at 621°C to achieve a hardness of Rockwell C 30-33.

## P/M FORGED PROPERTIES

Typical microstructures of heat treated 4640 P/M steel forgings are shown in Figure 1. In the unetched condition, Figure 1a, the microstructure was relatively clean throughout with no residual porosity or inclusions. The etched microstructure, Figure 1b, is characterized as finely tempered martensite and shows no evidence of prior particle boundaries.

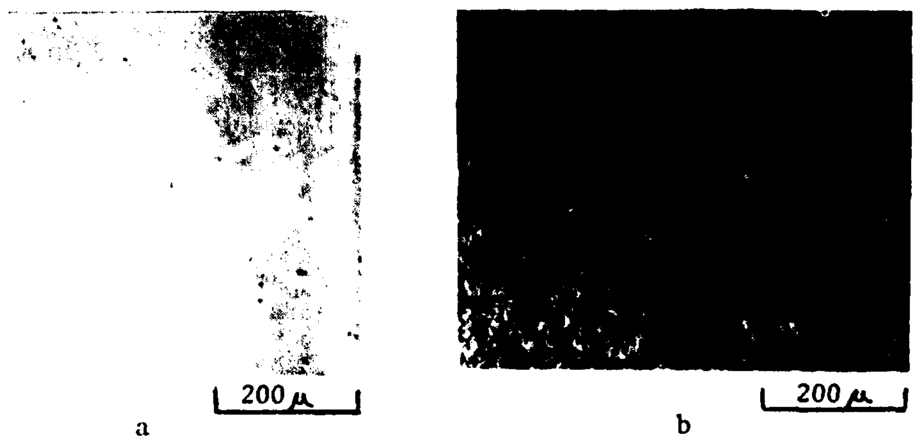



Figure 1. Unetched (a) and etched (b) microstructures of 4640 P/M steel forgings

The ultimate tensile and yield strengths of forged samples for different densities are shown in Figure 2. These properties were determined using standard R2 tensile bars (ASTM A370-E8). Ultimate tensile strengths and yield strengths were comparable to wrought 4640 material providing densities of 98 percent or higher were obtained. The excellent properties were achieved in the transverse as well as the longitudinal direction; thus, exhibiting the uniformity and fineness of the grain structure of the P/M forgings.

Elongation and reduction of area values for P/M forgings are shown in Figure 3. A very strong dependence on the final forged density is evident. As shown in Figure 4, these properties are also

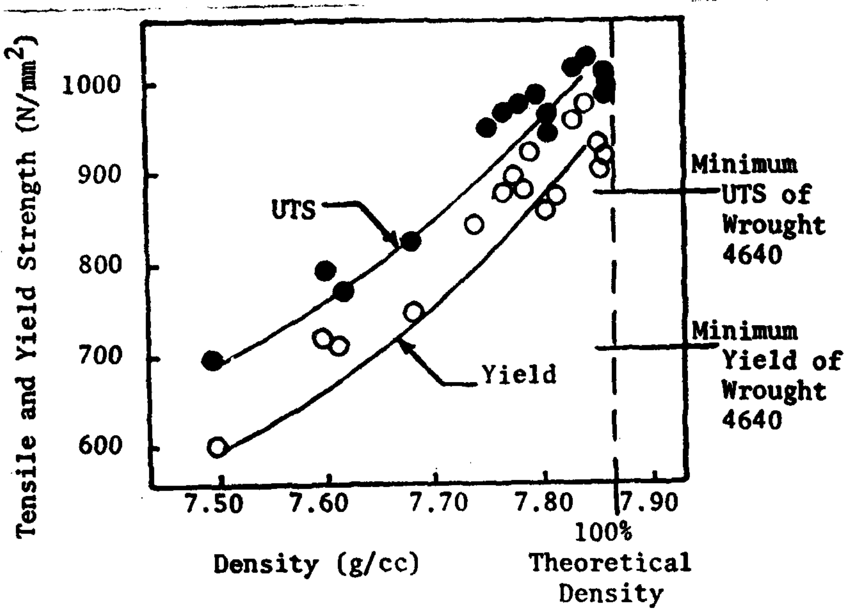



Figure 2. Tensile and yield strength vs. density of P/M steel forgings

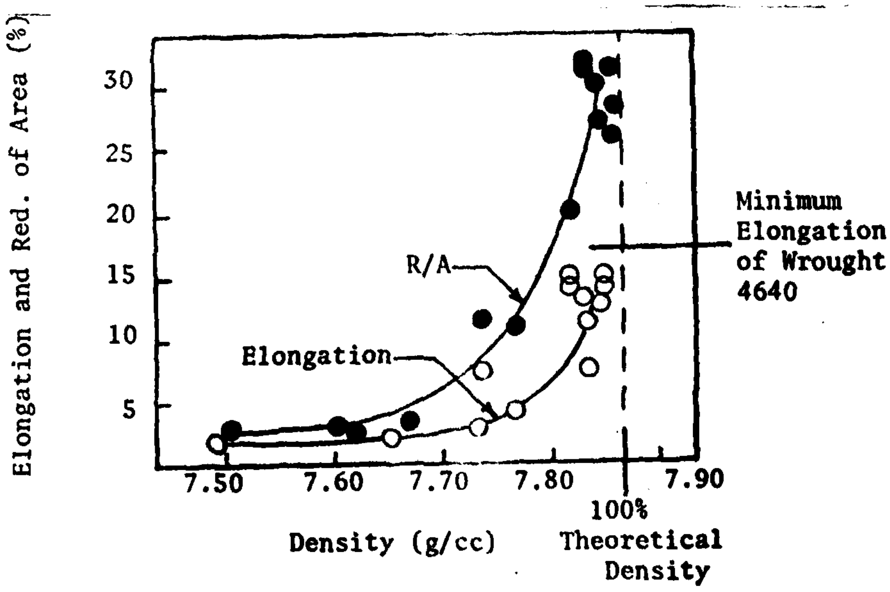



Figure 3. Reduction of area and elongation vs. density of P/M forgings.

very sensitive to oxygen content. To obtain ductilities equivalent to wrought materials requires a density of at least 99.5 percent of theoretical or better and an oxygen content below 300 ppm.

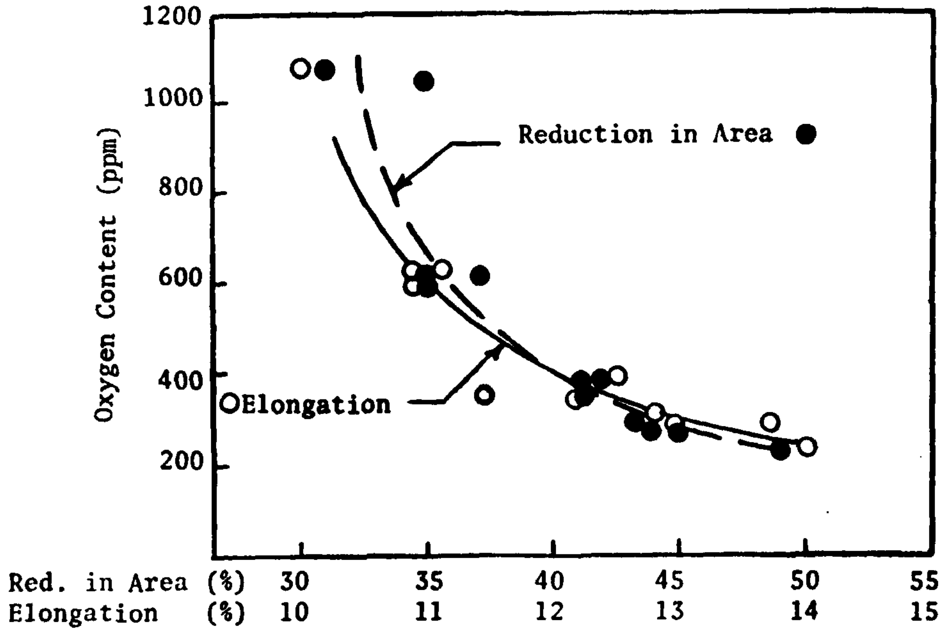



Figure 4. Reduction in area and elongation of P/M steel forgings as a function of oxygen content.

The response of P/M forgings to various heat treatments is shown in Figure 5. For comparison typical tensile properties of wrought 4640 (AMS specification 6317B) are shown. Tensile and yield strengths of the P/M forgings are shown to be comparable to the wrought material. Of greater significance, however, the elongation and reduction in area values are shown to be comparable to the wrought 4640 material throughout the hardness range investigated.

The impact strength (Figure 6) is, as expected, strongly dependent on the forged density. As theoretical density is approached, a dramatic increase in impact strength is obtained. Impact strength values were also found to be strongly dependent on the oxygen content (Figure 7). The presence of inhomogeneties either as oxide inclusions or as residual porosity can have a very detrimental effect on the impact properties.

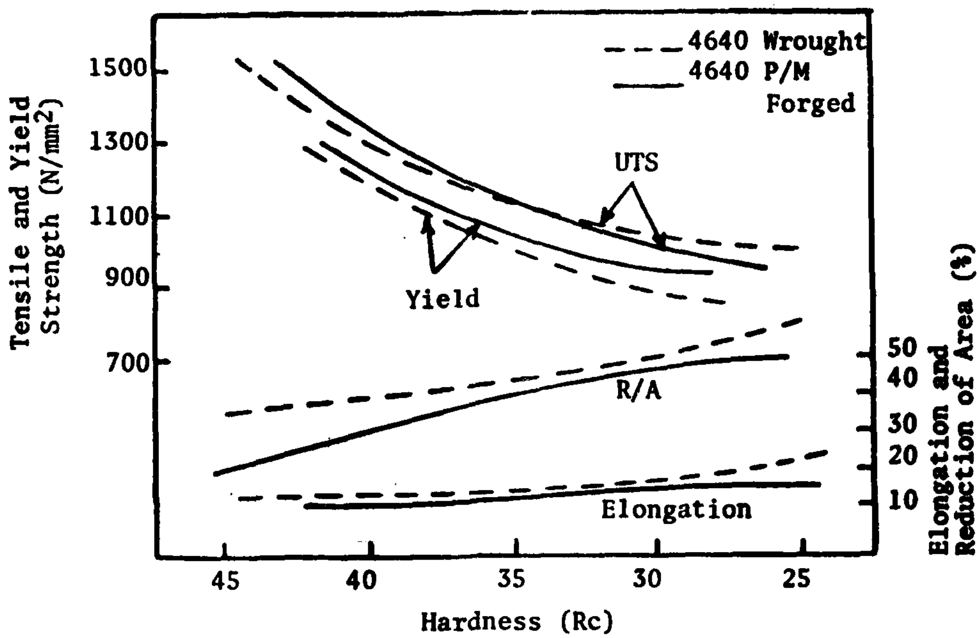



Figure 5. Response of 4640 P/M forgings to heat treatment

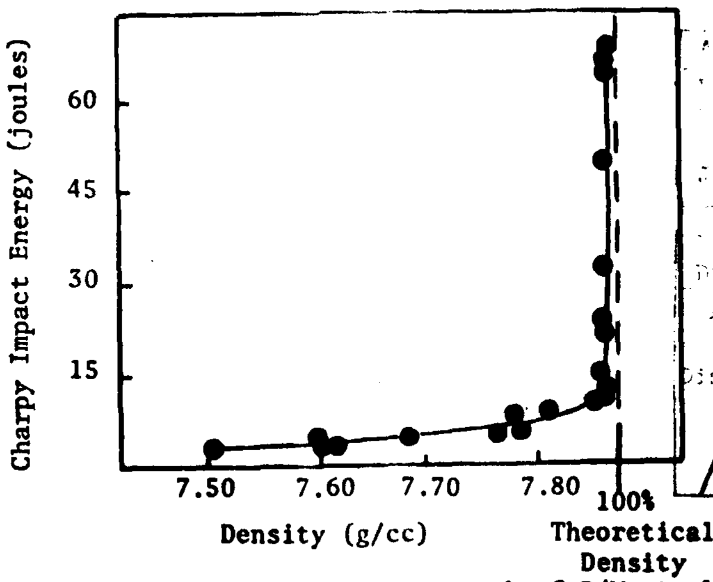



Figure 6. Charpy V-notch impact strength of P/M steel forgings as a function of density.

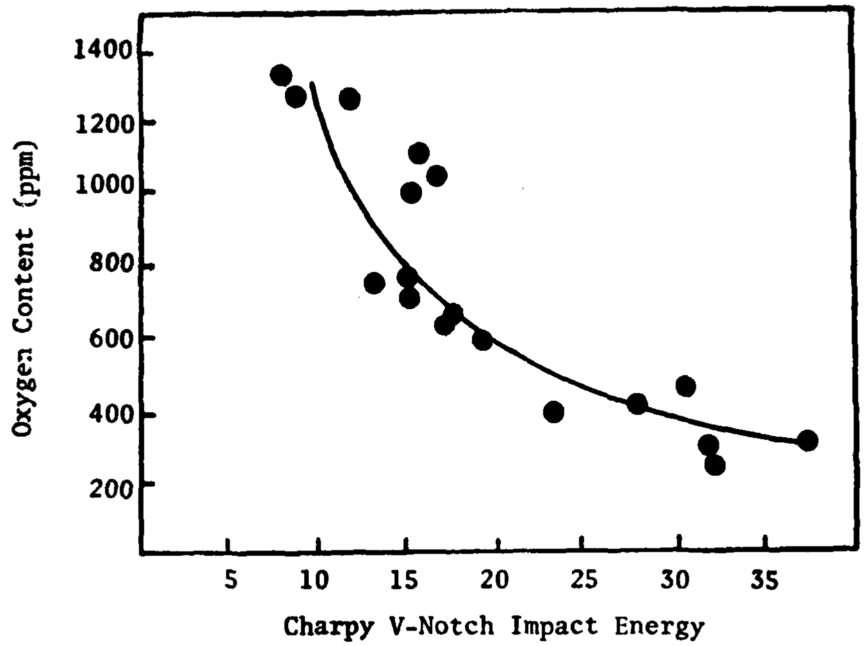



Figure 7. Impact energy of P/M steel forgings as a function of oxygen content

The results of the forging study have shown that P/M steel forgings can be competitive with wrought materials from a property standpoint. Mechanical property levels were reproducible and could be achieved routinely under proper processing conditions. Properties in the longitudinal direction were comparable to the wrought material whereas in the transverse direction they were found to be superior.

## SMALL ARM APPLICATIONS

The applicability of the P/M forging process to an actual high-performance weapon component was demonstrated with the accelerator for the .50 caliber M85 machine gun (ref. 6). The actual part is shown in Figure 8. The geometry of the accelerator was sufficiently complex to demonstrate the ability of the P/M process to precision forge a complex configuration with a minimum of secondary machining operations. A comparison between the operations involved in the conventional process and the P/M forging process to fabricate the accelerator is shown in Figure 9. The conventional method involves progressively working through a series of dies which plastically form the metal into the desired shape. Excess stock, which is necessary


Figure 8. Accelerator for .50 caliber M85 machine gun

Figure 9. Pictorial comparison of conventional forging and P/M forging processes for producing forged accelerator

in order to completely fill the die, remains in the form of flash and must be trimmed. The final forging requires considerable machining before the desired part is obtained. In contrast, the P/M forging process utilizes a single flashless forging step and thereby reduces the number of machining steps necessary to obtain the final part. The areas requiring additional machining operations are indicated in Figure 10 by heavy lines. All other areas are forged to finish size.

A cost breakdown on the two processes for the fabrication of the M85 accelerator is shown in Table 2. The die costs for the P/M forging process are not included in this estimate. Amoritization of the die costs would require a production run of approximately 1000 accelerators. However, once the die costs are amoritized, a cost reduction of approximately 50 percent is projected.

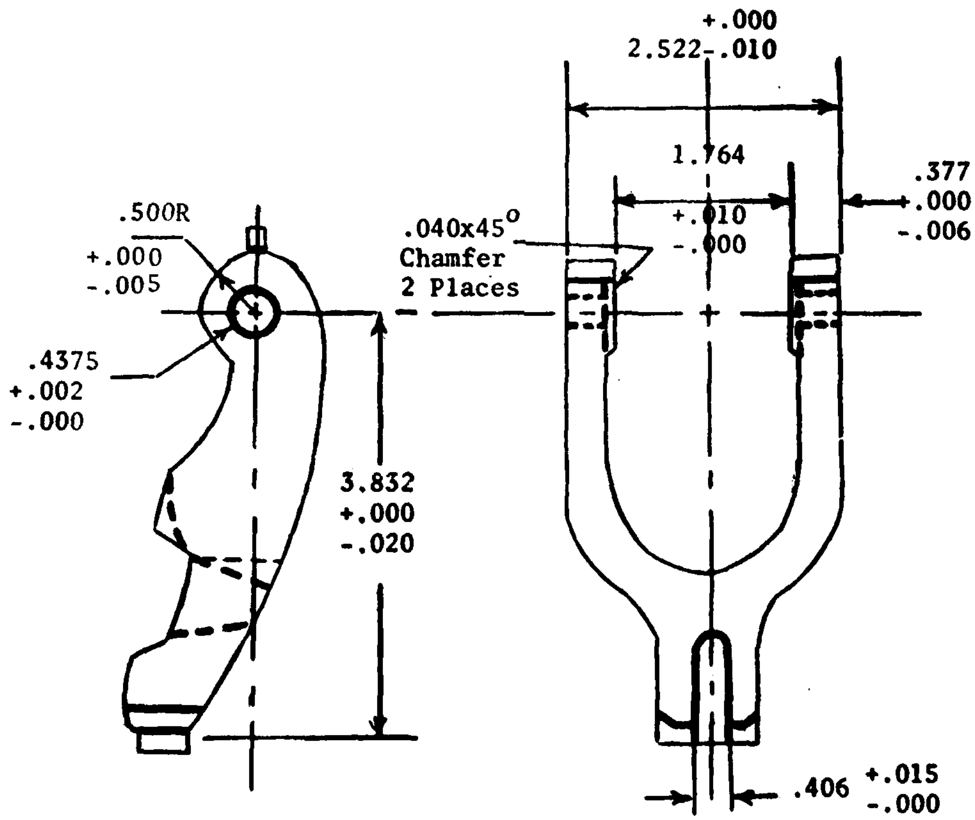



Figure 10. The as-forged accelerator with the post-forge machining operations indicated by heavy lines.

Table 2. *Cost breakdown - conventional forging vs. P/M forging accelerator for .50 cal M85 machine gun

| Conventional Process | | | | P/M Forging Process | | | |
|---|---|---|---|---|---|---|---|
| Operation | Standard Hrs/Pc | $/Pc | Setup Hours | Operation | Standard Hrs/Pc | $/Pc | Setup Hours |
| Heat & Forge | .0670 | 2.35 | 3.0 | Compact | .0200 | 0.70 | 4.0 |
| Trim | .0083 | 0.29 | 1.0 | Sinter | .0025 | 0.09 | - |
| Coin | .0083 | 0.29 | 1.0 | Forge | .0200 | 0.70 | 3.0 |
| Heat Treat* | .1600 | 5.60 | - | Heat Treat | .0800 | 2.80 | - |
| Sandblast | .0300 | 1.05 | - | Sandblast | .0300 | 1.05 | - |
| Machine | .8012 | 28.04 | 60.3 | Machine | .2699 | 9.45 | 16.6 |
| Finish | .1882 | 6.59 | 1.1 | Finish | .1882 | 6.59 | 1.1 |
| Material | - | 1.50 | - | Material | - | 0.26 | - |
| Totals Standard Hours | 1.2630 | $45.71 | 66.4 | Totals Standard Hours | .6106 | $21.64 | 24.7 |

*Cost of heat treat is proportional to weight of unmachined part.

The belt retaining pawl shown in Figure 11 is an example of another part found in the M85 machine gun that could be fabricated by P/M forging. Currently, this part is machined from wrought bar stock. The P/M forging process could produce this part net except for the final cross hole. This would result in a substantial cost savings. A summary of other possible parts in the M85 machine gun which could be cost effectively produced by P/M forging is listed in Table 3.

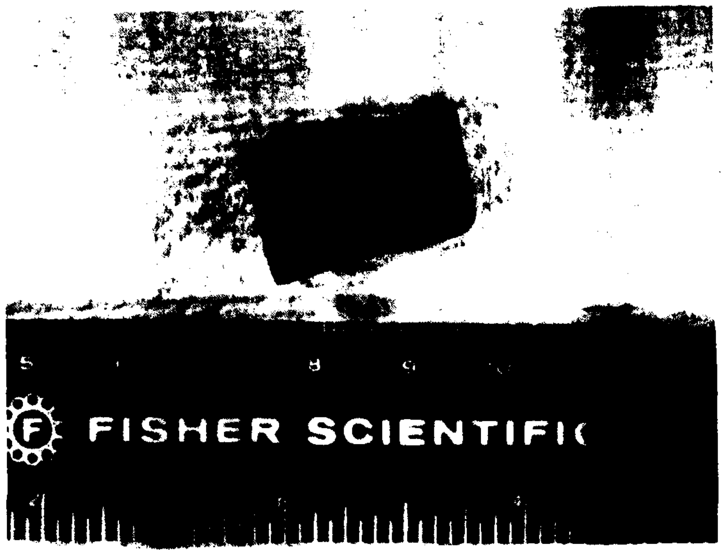



Figure 11. Belt retaining pawl for .50 caliber M85 machine gun

The .50 caliber M2 machine gun, likewise, has a variety of parts that can be fabricated by P/M forging. A partial listing is given in Table 4. As with the M85, the accelerator in the M2 is a prime candidate. The M2 accelerator is shown in Figure 12. A cost savings of approximately 50 percent could be realistically projected for this part, considering its similarity to the M85 accelerator. Other parts such as the alternate feed bolt, aligning pawl, and extractor have geometries similar to the accelerator and can be P/M forged with a minimum of secondary machining operations.

The 7.62mm M60 machine gun parts that could be fabricated by P/M forging are listed in Table 5. The sear, Figure 13, is an ideal part. Its configuration is such that it could be made to net shape requiring no further machining or, if desired with only a minimal amount of machining at the corners. This would be far more cost effective than the current method of machining from wrought bar stock. The barrel extension clamp (Figure 14) used in the M60 machine gun is likewise

Table 3. .50 caliber M85 machine gun parts having P/M forging fabrication potential

| Part No. | Nomeclature |
|---|---|
| 7790977 | Accelerator |
| 7790978 | Housing, Accelerator |
| 7790985 | Block, Barrel Latch |
| 7709087 | Latch, Barrel |
| 7791278 | Interlock, Barrel Extension |
| 7791378 | Retainer, Cartridge Case |
| 7792923 | Block |
| 7793074 | Selector, Rate |
| 7793076 | Cylinder, Time Delay |
| 7793083 | Cam, Latch |
| 7793132 | Detent, Cover |
| 7793157 | Trigger |
| 7793193 | Extractor, Small Arms Cartridge |
| 7793220 | Disconnector |
| 7793222 | Pawl, Cartridge Stop |
| 7793225 | Housing, Return Feed |
| 7793230 | Latch, Cover |
| 7793232 | Ramp, Guide Cartridge |
| 7793244 | Pawl, Cartridge Guide |
| 8448210 | Latch, Back Plate |
| 8448226 | Pawl, Belt Retaining |
| 8448227 | Slide, Belt Feed |

Table 4. .50 caliber M2 machine gun parts having P/M forging fabrication potential

| Part No. | Nomeclature |
|---|---|
| 5351220 | Slide, Sear |
| 5504059 | Bracket, Belt Holding Pawl |
| 5504060 | Latch, Bolt |
| 5504061 | Bracket, Bolt Latch |
| 5504065 | Extractor |
| 5504070 | Bracket, Top Plate |
| 6008913 | Pawl, Feed Belt |
| 6008928 | Latch, Cover |
| 6008975 | Pawl, Aligning Cartridge |
| 6528256 | Bolt, Alternate Feed |
| 7161302 | Breech Lock |
| 7313081 | Pawl, Belt Holding |

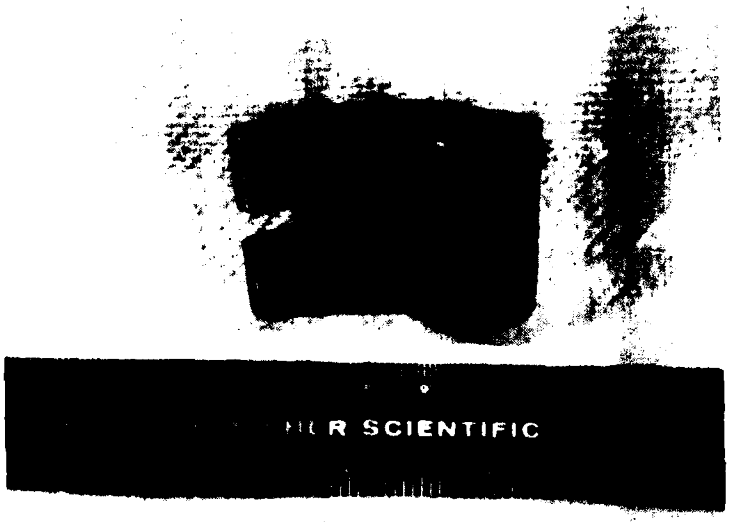



Figure 12. Accelerator for .50 caliber M2 machine gun

Table 5. 7.62mm M60 machine gun parts having P/M forging fabrication potential

| Part No. | Nomeclature |
|---|---|
| 7269083 | Plunger, Extractor |
| 7269088 | Actuator, Cam |
| 7269116 | Guide, Cartridge Front |
| 7269117 | Guide, Cartridge Rear |
| 7269136 | Latch, Cover |
| 7269147 | Handle, Lever |
| 7269201 | Stop, Guide |
| 7269209 | Sear |
| 7269284 | Base, Rear Sight |
| 7269285 | Knob, Windage |
| 7269288 | Cap, Leaf Frame |
| 7269291 | Knob, Elevation |
| 7269319 | Hinge, Shoulder Rest |
| 7269332 | Pawl, Cartridge Retainer |
| 7790907 | Extractor |
| 7791525 | Plug, Bolt |
| 7792093 | Plug, Gas Cylinder |
| 7793010 | Pivot, Bipod |


Figure 13. Sear for 7.62mm M60 machine gun

a prime candidate. It can also be made to net shape except for the drilled and tapped hole on the side. Such complexities as exhibited by these examples can be easily formulated in the parts by P/M forging; thus, eliminating many of the costly machining operations presently used.

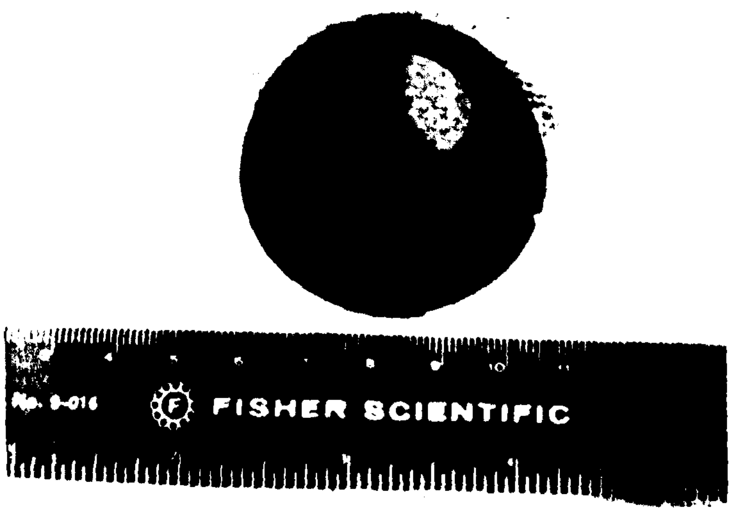



Figure 14. Barrel extension clamp for 7.62mm M60 machine gun

## CONCLUSIONS

The applicability of the P/M forging process to fabricate high performance weapon components was demonstrated. Property levels were shown to be comparable to the same parts machined or forged from wrought bar stock. Major cost advantages were realized through more efficient material utilization and a reduction of machining operations. The cost effectiveness of the process, however, was not fully realized until amortization of the P/M compacting and forging dies was achieved. This usually necessitated an initial production run from 1,000 to 3,000 parts depending on the complexity of the part to be fabricated. Once this has been accomplished, a variety of parts from the M2, M60 and M85 machine guns can be fabricated with cost reductions ranging up to 50 percent.

## REFERENCES

1. "Forging of P/M Preforms", Modern Developments in Powder Metallurgy, (Ed. H.H. Hausner), Plenum Press, NY, 1971, Vol. 4, pp 369-523.

2. R. F. Halter, "Recent Advances in the Hot Forming of P/M Preforms", Modern Developments in Powder Metallurgy, (Ed. H.H. Hausner), Plenum Press, NY, 1973, Vol. 7, pp. 137-152.

3. R. Gold, "Production P/M Hot Forming is Here", Precision Metal, Vol. 33, No. 11, 1975, pp. 23-26.

4. Gustafen, D. A., "HD:P/M = High Density Parts via P/M Techniques", Metal Progress, April 1972, pp. 49-58.

5. Lally, F.T. and Toth, I.J., "Forged Metal Powder Gears", Technical Report No. 11960, US Army Tank Automotive Command, Warren, MI, September 1974.

6. F. T. Lally, I. J. Toth and J. DiBenedetto, "Forged Metal Powder Products", SWERR-TR-72-51, Rock Island Arsenal, Rock Island, IL, August 1972.

NL

DATE

ILME